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13. ABSTRACT *(Maximum 200 words)*

This instrumentation grant supported the purchase of a small supercomputer for cognitive brain imaging and other large 3D dataspaces. The machine that was purchased was an SGI (Silicon Graphics) Origin 2000 parallel supercomputer with 14 CPU's, 7 gigabytes of main memory, 750 gigabytes of disk storage, and 5 terabytes of fast tape storage. In addition, 6 SGI Unix workstations were purchased for graphics display and processing, and 9 NT/Intel workstations for local data analysis. The machines are networked in a 100mbit LAN. The area of computing in functional brain imaging and other massive 3-D dataspaces has extraordinary scientific, medical, and commercial potential. The potential application to DoD is the ability to measure brain function during the performance of high-workload tasks, such as decision-making, communication, and visualization. The measurement of the brain function provides a new way to measure cognitive workload, its limitations, and its efficiencies. These new methods have implications for the selection and training of personnel, and for the design of human-computer interfaces. The research develops methods for measuring brain activation in the cortex during the performance of high level cognitive tasks and in dynamic decision making, in order to evaluate the cognitive workload imposed on an operator by various tasks, situations, interfaces, or instruments. The fMRI data are acquired at a high rate (one brain slice about 5 mm thick consisting of 64x128 voxels approximately every 200 msec), in tasks taking a total of about 15 minutes each. The data are then subjected to signal processing and statistical modeling techniques, to discover the spatial and temporal patterns of cortical activation in a network of brain areas that underlie higher-level cognition.

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Defense University Research Instrumentation Program (DURIP) Final Report

Title: Parallel Supercomputing in Cognitive Brain Imaging and Other Massive 3-D Dataspaces
Sponsor: Air Force Office of Scientific Research
Grant Number: F49620-98-1-0186
Principal Investigator: Marcel Adam Just, Carnegie Mellon University
Funding Period: March 1, 1998 to February 28, 1999

Abstract

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The area of computing in functional brain imaging and other massive 3-D dataspaces has extraordinary scientific, medical, and commercial potential. The potential application to DOD is the ability to measure brain function during the performance of high-workload tasks, such as decision-making, communication, and visualization. The measurement of the brain function provides a new way to measure cognitive workload, its limitations, and its efficiencies. These new methods have implications for the selection and training of personnel, and for the design of human-computer interfaces.

The research develops methods for measuring brain activation in the cortex during the performance of high level cognitive tasks and in dynamic decision making, in order to evaluate the cognitive workload imposed on an operator by various tasks, situations, interfaces, or instruments. The fMRI data are acquired at a high rate (one brain slice about 5 mm thick consisting of 64x128 voxels approximately every 200 msec), in tasks taking a total of about 15 minutes each. The data are then subjected to signal processing and statistical modeling techniques, to discover the spatial and temporal patterns of cortical activation in a network of brain areas that underlie higher-level cognition. The research develops measurement and modeling techniques that provide useful information about the functional 3-space properties of the data.

The main purpose of the machine is to develop and use new statistical and signal processing techniques to measure the brain activation underlying high level cognition and decision making, to ascertain the determinants of cognitive workload, and to significantly increase the throughput of the data analyses in various DOD-funded and other projects.

The choice of machine

Prior to the purchase of the machine, two vendors who bid for the equipment, HP (Hewlett-Packard) and SGI (Silicon Graphics), were asked to do benchmark tests using our application software. The main criterion for choosing the SGI machine was its suitability to our application.

A theoretical analysis led us to believe that the Hewlett-Packard machine would perform better. However the benchmark tests showed that the SGI machine was approximately twice as fast at performing our application. Neither the SGI nor the HP engineers could explain the SGI superiority. Two additional considerations were that the SGI machine was cheaper than the HP machine, and that software developed at other brain imaging centers was more often written for SGI than HP. The large margin of advantage of SGI dictated that we buy the SGI machine.

There were also two disadvantages of the SGI machine, but they were mitigated. Our previous software ran under the HP variant of Unix, namely HPUX, whereas the SGI machine uses the SGI version of Unix, namely Irix. Buying the SGI machine required some porting of our software. After the SGI machine was purchased, the porting took only a matter of weeks. A second disadvantage was that the SGI machine generated more heat than the HP, requiring an additional air-conditioning unit.

The new machine has enormously facilitated the throughput of processing and has enhanced the ability to store large amounts of data online. We no longer experience delays in analyzing the data, obtaining immediate feedback on the progress of the experiments. In the past we have had to do the analysis during an overnight run, taking several hours to process 15 minutes of data. With the new machine, the analysis of minutes of data can be done in approximately 15 minutes.

Another large benefit is that many studies can be kept available simultaneously. This is important because the data for many studies are acquired concurrently and analyzed concurrently. In addition, the large archival capability provides a growing database on which various specific hypotheses can be tested, and which can be used for data mining techniques. This capability allows meta- analyses of the data to be easily performed. Instead of restricting a data analysis to the findings from 15 participants in a particular study, it is now possible to examine a growing database of hundreds of participants.

Here is a brief example. In the spring of 1999 there was a scientific report that an anatomical examination of Albert Einstein's brain found that his angular gyrus was unusually large. We had in our database the anatomically-segmented brain images of approximately 100 college students and the students' performance on various psychometric scores of spatial ability and verbal ability. The meta-analysis showed very little correlation between the size of the angular gyrus and performance on these abilities. The same lack of correlation occurred for several other brain areas. Although this example was anatomical, we focus on the functional imaging data, indicating which brain areas became activated at which point in time.

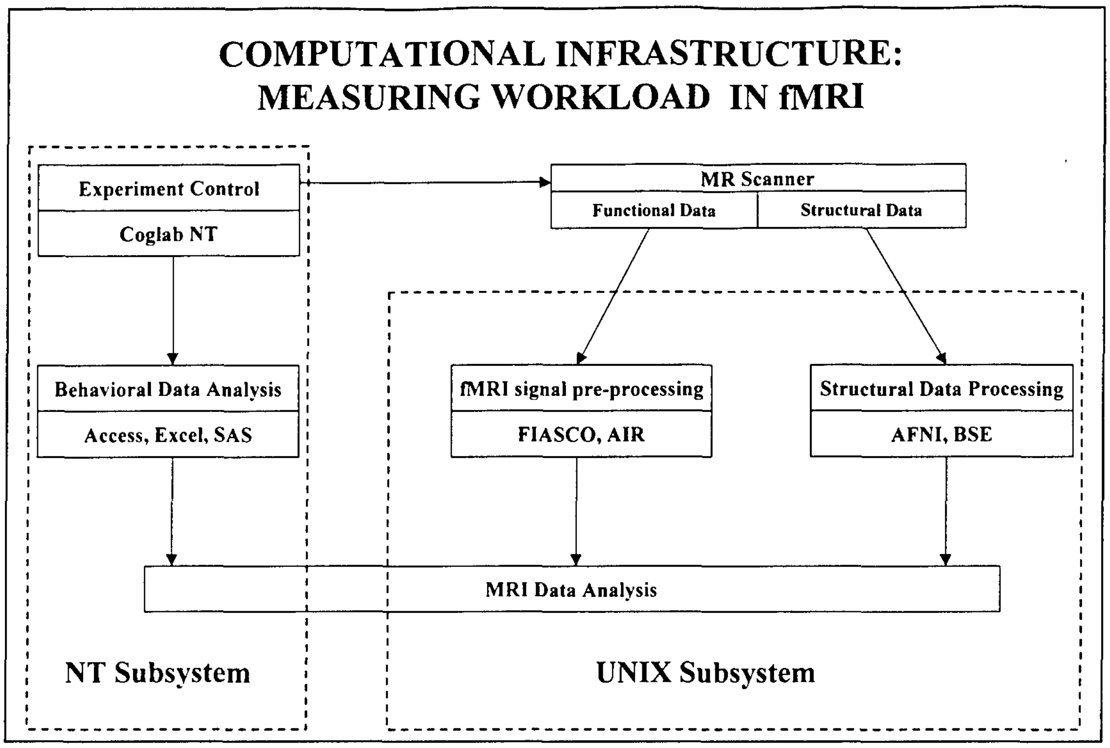
An fMRI study produces time-series data that represent the dynamic behavior of a network of brain areas during cognitive task performance, and are separable into the images associated with performance of particular items in a test. One image (the aggregate of all the slice planes) in this time series may contain on the order of 15,000 – 30,000 voxels, each of which measures the response of a 50-mm^3 region of the brain. Images of 15,000 voxels can be acquired at the rate of one approximately every 1000 msec with high field (3 Tesla) echoplanar imaging. The acquisition rate is about 100 GB of raw fMRI data per year.

We are developing new tools for fMRI data analysis that (1) broaden the range of background information that goes into the data analysis, incorporating prior knowledge that includes explicit models of cognitive function, knowledge of the neuroanatomy of cortical connections, and knowledge about the gross mapping of function to brain regions; (2) deepen the data analysis by modeling the dependence of cortical activity over time and space (e.g., to discover how voxel activities at time t correlate with activity of brain region x at time $t+1$); and (3) combine information collected across many human subjects and tasks.

Equipment Purchased

Vendor	Qty	Description	Cost
Silicon Graphics	1	Parallel Computer Server System – SGI Origin 2000	489,411
Silicon Graphics	6	Octane Workstations	71,982
Silicon Graphics	2	Intel/NT graphics Workstations	8,904
Dell Computer	7	Intel/NT Workstations	19,585
Micron Electronics	2	NT Laptops	7,086
Dreher Business Machines	2	Tektronix Color Printer	5,608
Dreher Business Machines	1	HP Laserjet Printer	1,282
Nat'l Res. Council of Canada	1	Evident Software (portion charged to DURIP)	500
SAS Institute	1	SAS System – Statistical Software	6,570
Misc. other expenses			
Equipment Total			$610,928

The following figures show the computational infrastructure and summarizes hardware and software currently used:



HARDWARE AND SOFTWARE

- **UNIX subsystem**

  - Hardware:
  14 CPU Origin 2000 server, 5 terabyte tape library, UNIX workstations.
  - Software :
  Commercial systems (AVS, SAS, S-PLUS, IDL, Networker)
  Scientific MRI packages (FIASCO, AFNI, AIR, BSE, EVIDENT)
  In-house software - custom AVS modules and networks, VOXCOR, template-mapping software, a variety of shell scripts and executables.

  In-house software utilizes modern parallel multiprocessing and computer graphics.

- **NT subsystem**
  - Commercial software: Access, Excel, SAS.
  - In-house software : CoglabNT.